Predicting Covid-19 Hospital Admissions in England

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A predictive model for Covid-19. The Extended Gompertz Function model[1] uses observed data to predict the course of Covid-19 waves with sufficient accuracy to plan for healthcare demands. It can be used for Covid-19 cases, hospital admissions, ICU admissions and deaths. We illustrate it for hospital admissions as these are more informative than cases, are reliable indicators as they are reported without retrospective revisions (albeit after a two day lag) and, most importantly, because uncertainty about demands on the healthcare system has been the main driver of extreme responses by governments–in the UK and world wide.

The model in a nutshell. Unlike the conventional epidemiological models, which are not designed to make predictions[2], but which have all too often been presented as firm forecasts of the future, our model is phenomenological in nature. Like Galileo's assertion that projectiles follow parabolic paths, it is designed to predict what *will* happen, not *why* it will do so.

The model predicts that Covid-19 waves follow a sequence of alternating phases of linear growth (the endemic phases) and Gompertz Function[3]growth (the outbreak phases). During the linear growth phases, extrapolating the current line of best fit provides accurate forecasts. During the Gompertz Function growth phase the best Gompertz Function fit to cumulative admissions data allows us to make predictions by extrapolating forward along the fitted curve.The prediction errors become smaller, and remain smaller for longer, as the outbreak progresses. Typically within about two weeks prediction errors remain below 25% for at least a week out of sample and in three to four weeks the errors will remain below 10% for at least that long.

Bounds on growth reduce uncertainty at the inception of new outbreaks. Even though we know that each outbreak will follow Gompertz Function growth and become highly predictable, initially the Gompertz Function fits extends only for a few days into the future with prediction errors of less than 10%. To reduce this uncertainty, we have designed a process that produces good bounds for growth of cumulative Covid-19 events. These bounds reliably contain cumulative event levels until the Gompertz Function fits' prediction errors remain below 10% for at least a week out of sample.

The Omicron outbreaks in England We began tracking English Covid-19 hospital admissions in real time in November 2021. In November, they were in the linear growth phase and we expected a new Gompertz Function growth phase should take place in the normal 'Flu Season' window. Our analysis of the transition told us that Gompertz Function growth started on 6 December 2021[4]. The Gompertz Function growth phase evolved as we predicted. We observed the Omicron outbreak's hospital admissions make the transition to linear growth on 8 February 2022. By 5 March 2022 we detected the start of a new Gompertz Function growth phase which was driven by the Omicron BA.2 sub-variant. That phase ended on 7 May with linear growth until the most recent Omicron wave, primarily driven by BA.5, began on 9 June. This phase peaked on 8 July and cumulative admissions growth reverted to the linear mode on 16 August.

Covid-19 Forecasting The Extended Gompertz Function model is easily implemented with standard statistical software. For information about our forecasts of Covid-19, including transitions between phases and estimating growth bounds, contact us at *OmegaAnalysis@protonmail.com*.

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[1]Ana Cascon and William F. Shadwick 2021 Predicting the course of Covid-19 and other epidemic and endemic disease. `https://www.medrxiv.org/content/10.1101/2021.12.26.21268419v1`

[2]As Graham Medley, chairman of the UK's SPI-M modelling group, has been at pains to explain, providing scenarios is the, often misunderstood, purpose of the Covid-19 modelling presented to the UK SAGE committee.`https://www.spectator.co.uk/article/what-the-media-gets-wrong-about-sage-s-models`

[3]The Gompertz Function is defined by $Gompertz(t, a, b, N) = Ne^{-e^{-(at+b)}}$.

[4]We made the observation that linear growth was over using the data to 5 December 2021. As English Covid-19 hospital admission data lags by two days, we only knew this on 7 December and similarly with other dates quoted.

Omicron, Omicron BA.2 and Omicron BA.4-BA.5 Hospital Admissions in England

Bounds on cumulative growth Our growth bounds are created when we detect a transition from linear growth to the next Gompertz Function outbreak phase. They are intended to contain cumulative admissions until the Gompertz Function fits' prediction errors remain below 10% for at least a week. Because Covid-19 outbreaks vary greatly in scale, only data from the recent past is informative about a new outbreak. When a new Gompertz Function growth phase is detected we use the most recent three weeks of data to estimate the bounds. We use Extreme Value Theory techniques to make estimates of admissions in excess of those in the sample. We calculate the following: $Level_1$ is the average conditional on exceeding the sample maximum. $Level_2$ is the average conditional on exceeding $Level_1$ and $Level_3$ is the average conditional on exceeding $Level_2$. These are direct estimates of the variability in admissions data.The bounds are linear growth at a rate of $Level_1$, $Level_2$ and $Level_3$ admissions per day.

The slope of the linear fit in November 2021 and these estimated Levels were all about half of what we had observed in December 2020–hence our correct prediction that hospital admissions in the Omicron wave would only be about half of what we had experienced in the 2020-2021 winter outbreak.

Growth bounds versus Gompertz Function confidence intervals. The standard errors of the Gompertz Function fit parameters give us a way of looking at uncertainty about the current Gompertz Function's fit to the data–but this changes with each update and is less informative than bounds on the growth of daily admissions. Our bounds, given at the outset of each outbreak, have a natural 'cascade'. You can ignore $Level_2$ and $Level_3$ until $Level_1$ is breached and ignore $Level_3$ until $Level_2$ is breached. As long as the observed daily admissions in excess of the sample maximum are, on average, below $Level_1$, growth in cumulative admissions *must* stay below linear growth at $Level_1$ admissions per day. Likewise for breaches of $Level_2$ and $Level_3$. Once the $Level_1$ bound is breached the $Level_2$ bound will continue to hold for several days and likewise when the $Level_2$ bound is breached.This can be seen clearly in Figures 1–4 .

The Omicron and Omicron BA.2 waves Figure 1 shows the bounds calculated on 5 December 2020. The upper bound was only breached in the first week of January 2022. By 29 December 2021, the Gompertz Function fit had sufficient predictive power that its out of sample errors never exceeded 9.2%. By 8 February, Omicron had reached an endemic state and we observed linear growth in hospital admissions once again.

This only lasted a few weeks before the Omicron BA.2 variant started driving another outbreak. We observed this transition on 8 February 2022 and calculated bounds on growth shown in Figure 2. These bounds were all approximately 60% larger than the ones at the onset of the Omicron wave in December 2021, leading us to predict that the Omicron BA.2 wave would generate about 60% more hospital admissions than Omicron did. The actual admissions were larger than the first Omicron wave but only by 29%.

The Gompertz Function fit made after ten days, on 15 March, predicted the out of sample admissions for six days with errors below 30% but the fit a week later had errors below 20% for a week and below 30% for eleven days. The accuracy improved quickly. Figure 2 shows the Gompertz Function fit on 28 March for which the prediction errors remained below 10.5% for a week out of sample and below 20% for another week. Within a few days the predictive power of the Gompertz Function fit had again increased significantly. Figure 3 illustrates the fit from 3 April which had prediction errors below 10% for 12 days out of sample. Figure 4 shows the Gompertz Function fit from 9 April 2022 which had even better predictive power, with prediction errors below 4% for 11 days out of sample and below 6% until 1 May 2022.

Cumulative hospital admissions were (just) contained by the Level 3 bound (at the closest approach total admissions were only 0.15% below Level 3) and can be seen dropping away from it sharply. Figures 5 and 6 show that the Gompertz Function fits were converging quickly by the beginning of May.

The Omicron BA.4 and BA.5 wave The linear growth in hospital admissions from 8 May to 8 June was followed by another outbreak, this time driven by the BA.4 and BA.5 variants. The linear growth bounds are shown in Figure 7. The Level 3 bound was exceeded on 13 July, however the Gompertz Function fit from 11 July (also shown in Figure 7) has had errors of less than 1.25% for two weeks out of sample and less than 4% for six weeks. Figure 8 shows the fit with data to 15 August when Gompertz Function growth ended.

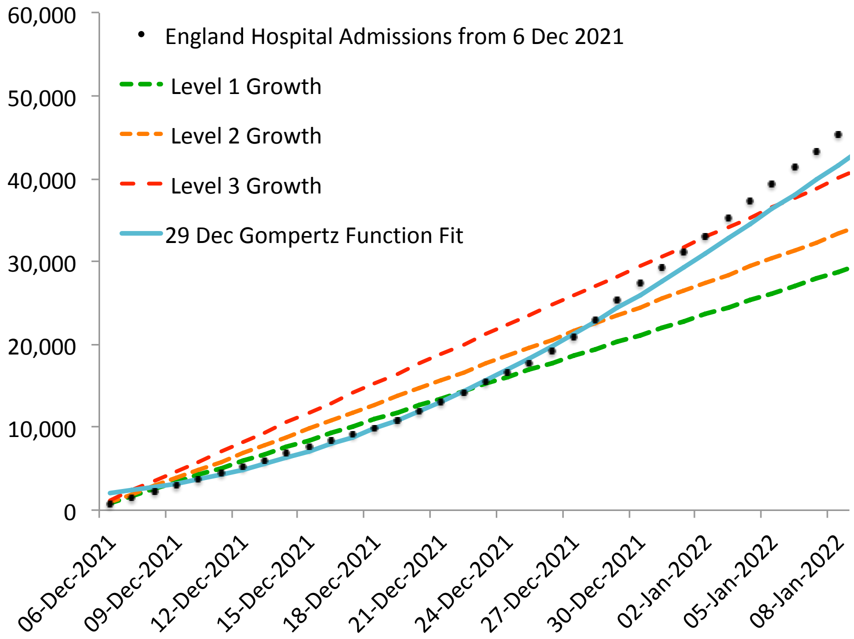

Figure 1: The 29 Dec 2021 Gompertz Function fit's prediction errors never exceeded 9.2%. The Level 3 bound was only breached in the first week of January, after our target level of predictive power had been achieved.

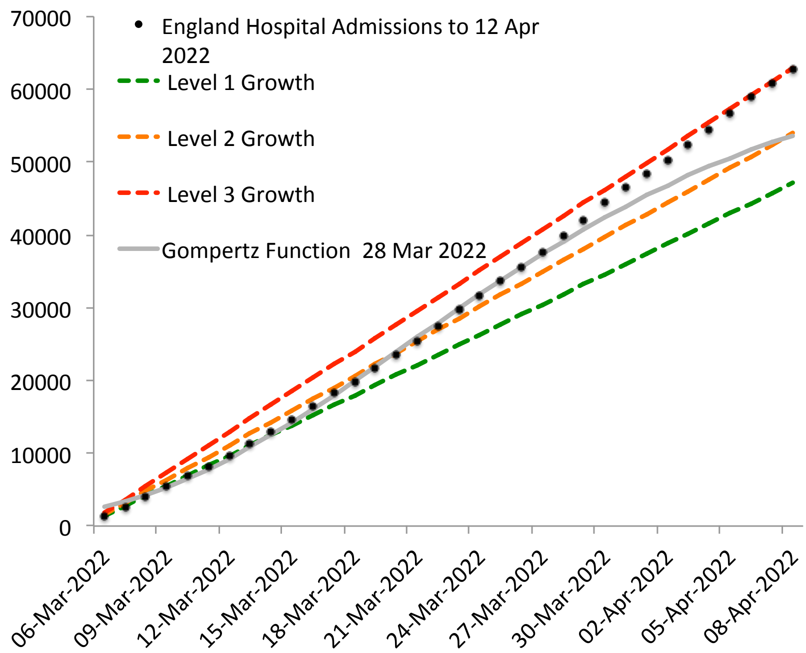

Figure 2: Covid-19 Hospital Admissions in England and Gompertz Function Fit made on 28 March, 23 days from the onset of the latest wave. Its prediction errors stayed below 20% for two weeks out of sample.

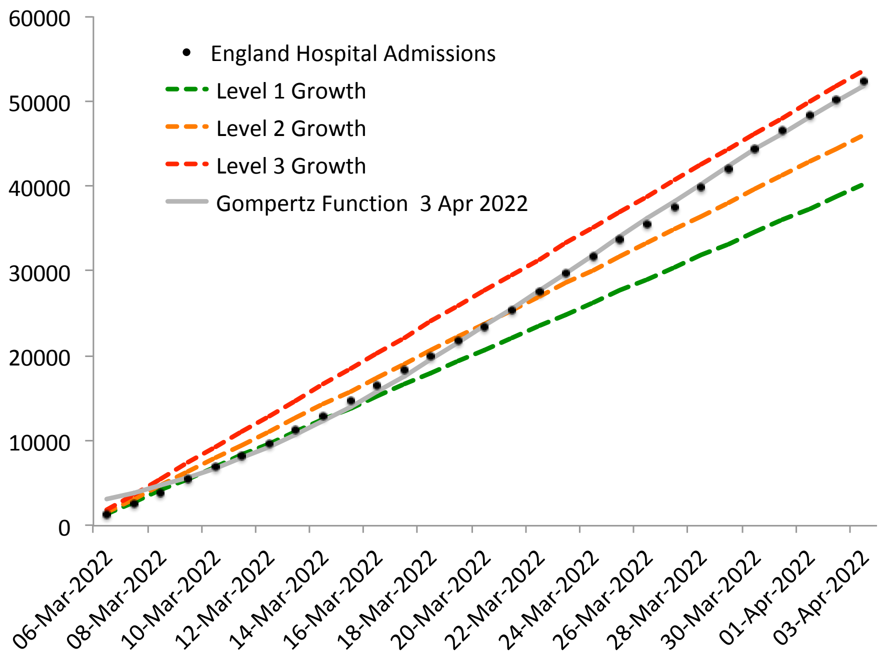

Figure 3: The Gompertz Function fit on 3 Apr 2022 had prediction errors below 8% for more than a week out of sample and below 10% for twelve days out of sample.

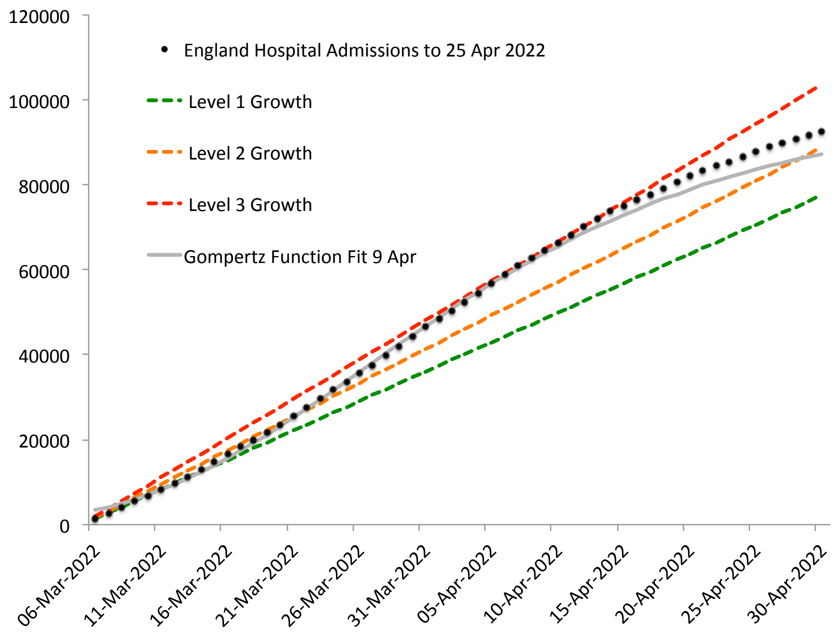

Figure 4: The Gompertz Function fit on 9 Apr 2022 had prediction errors below 4% for eleven days out of sample and below 6% through 30 April 2022.

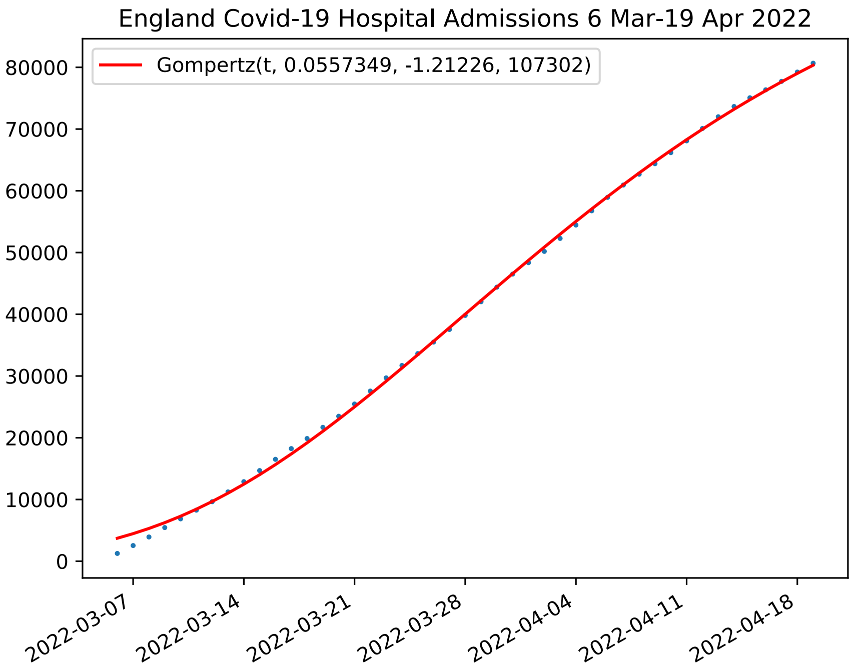

Figure 5: The Gompertz Function fit on 19 Apr 2022.

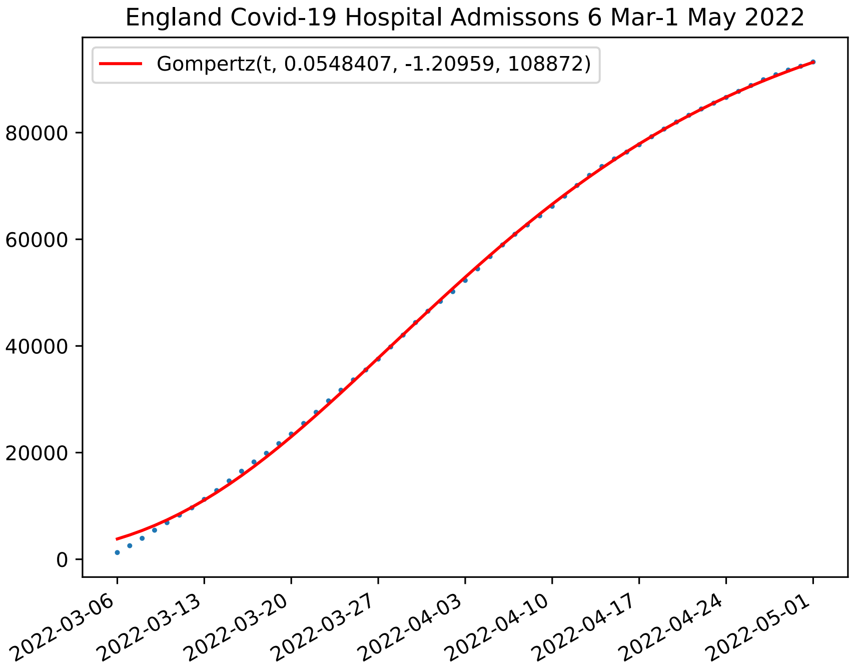

Figure 6: The Gompertz Function fit on 1 May 2022.

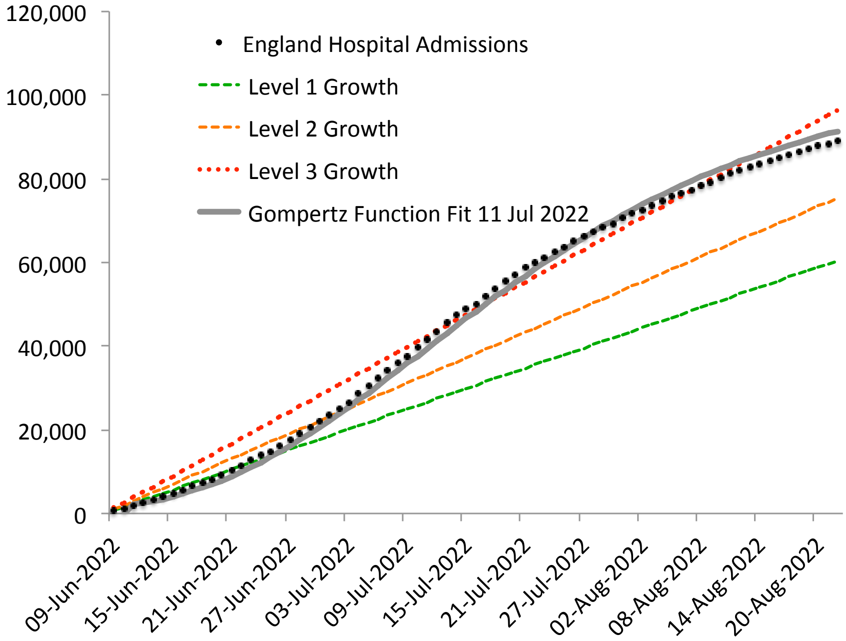

Figure 7: The Gompertz Function fit on 11 July 2022 had prediction errors below 1.25% for two weeks out of sample and below 4% for six weeks. The Level 3 Growth bound was exceeded on 13 July.

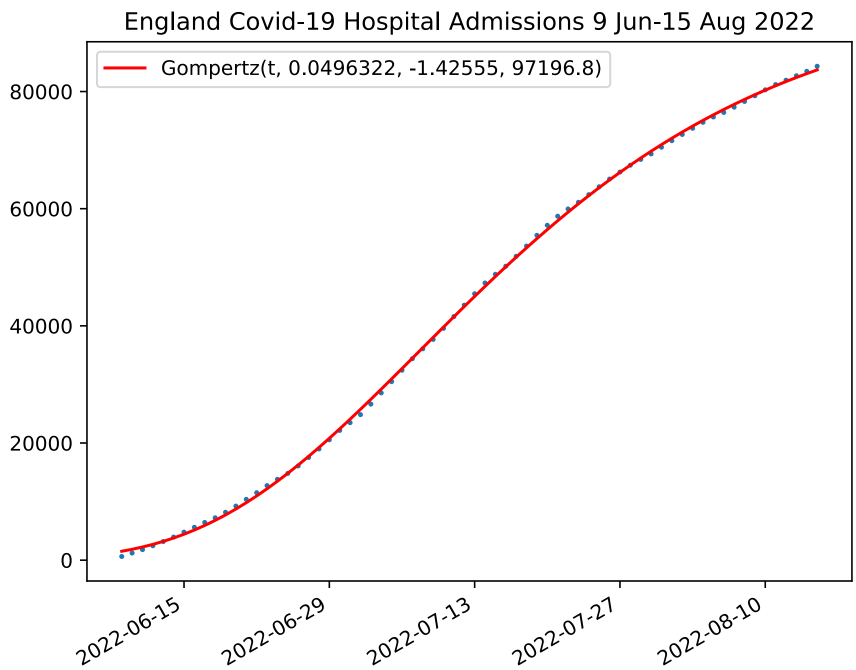

Figure 8: The Gompertz Function fit on 15 August 2022 when the Gompertz Function growth phase ended. The linear growth phase that began on 16 August likely signals the emergence of yet another a new variant.